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(54) Title: HEARING AID WITH PROPORTIONAL FREQUENCY COMPRESSION AND SHIFTING OF AUDIO SIGNALS

(57) Abstract

Apparatus and methods for audio compression and frequency shifting retain the spectral shape of an audio input signal (14) while compressing and shifting its frequency. The fast Fourier transform of the input signal is generated (16), to allow processing in the frequency domain. The input audio signal is divided into small time segments, and each is subjected to frequency analysis. Frequency processing includes compression and optional frequency shifting (18). The inverse fast Fourier transform function is performed (20) on the compressed and frequency shifted spectrum, to compose an output audio signal (22), equal in duration to the original signal. The output signal is then provided to the listener with appropriate amplification to insure audible speech across the usable frequency range.

HEARING AID WITH PROPORTIONAL FREQUENCY COMPRESSION AND SHIFTING OF AUDIO SIGNALS

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION:

5   The present invention relates to apparatus and methods for compressing and manipulating audio data.

DESCRIPTION OF THE PRIOR ART:

For some listeners with sensorineural hearing loss in the high frequency or other frequency ranges, providing audibility of
10   the speech signal in the frequency regions of hearing loss is not effective. These listeners are unsuccessful users of hearing aids.

It is possible to determine the specific frequency regions in which users are unable to use amplified speech, using a measurement technique known as correlational analysis.

15   The idea of frequency lowering speech is known, but has not thus far been successful. This is because if, in the process of frequency lowering speech, the important cues of speech recognition are transformed into a new form, recognition will be degraded or, at best, require large amounts of training for
20   listeners to learn to use the new cues. Several types of devices such as frequency transposers and vocoders have been tried for hearing impaired listeners with little success. These devices

typically shift a band of high frequencies by a fixed number of
Hertz to lower frequencies using amplitude modulation
techniques or the like. Often the shifted band is mixed with the
original low frequency signal. This produces an unnatural speech

5   signal which is not typically useful for hearing impaired
individuals.

An example of a commercially available hearing aid which
attempts to move sound signals into the frequency range that can
be heard by the hearing aid wearer, to increase the wearer's

10   comprehension of speech and other sounds, accomplishes this
task by compressing the audio signal in the time domain. The
TranSonic™ Model FT-40 MK II hearing aid, by AVR
Communications Ltd. slows down the audio signal to lower its
frequency, and then a "recirculation" circuit recycles the signal

15   from the storage device back to the input of the storage device to
mix with later signals. Other hearing aids have used
correlational analysis to process different parts of the audio
spectrum differently, according to linear predictive coding or the
like.

20   Human listeners are quite accustomed to recognizing at
least one type of frequency compressed speech. The variation in
sizes of the vocal apparatus between various speakers and
speaker types (e.g. males, females, and children) produces speech
that has different frequency contents. Yet most listeners easily

25   adapt to different talkers, and recognition is relatively
unaffected. One important unifying characteristic across various
individual speakers is that the ratios between the frequencies of
the vocal tract resonances (formant peaks) are relatively

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constant. In other words, the frequency differences between
speakers can be represented as proportional differences in
formant peaks, whereby each frequency is shifted upward or
downward by a fixed multiplicative factor. Thus, proportionally
5   frequency lowering or compression can compress the frequency of
a speech signal into the usable portion of the hearing range, while
retaining recognition. Similarly, proportionally compressing the
audio signal and shifting it into a higher portion of the sound
spectrum can offer increased recognition to individuals with
10   hearing deficits in lower frequency ranges.

A need remains in the art for apparatus and methods to
provide an understandable audio signal to listeners who have
hearing loss in particular frequency ranges, by proportionally
compressing the audio signal.

15   SUMMARY OF THE INVENTION

It is an object of the present invention to provide an
understandable audio signal to listeners who have hearing loss in
particular frequency ranges by proportionally compressing the
audio signal. The present invention achieves this objective by
20   maintaining the spectral shape of the audio signal, while scaling
its spectrum in the frequency domain, via frequency compression,
and transposing its spectrum in the frequency domain, via
frequency shifting.

BRIEF DESCRIPTION OF THE DRAWINGS

25   Figure 1 shows a block diagram of the compression and
frequency shifting process of the present invention.

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Figure 2 illustrates a simplified block diagram illustrating a first method of proportional compression according to the present invention.

5   Figure 3 illustrates a simplified block diagram illustrating a second method of proportional compression along with frequency shifting according to the present invention.

Figure 4 illustrates in more detail how the compression step of Figure 2 is accomplished.

Figure 5 illustrates in more detail how the compression
10   step of Figure 2 is accomplished, along with frequency shifting.

Figure 6 illustrates in more detail how the compression step of Figure 3 is accomplished, along with frequency shifting.

Figure 7 illustrates in more detail how the compression step of Figure 3 is accomplished, without frequency shifting.

15   DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Figure 1 shows a block diagram of the compression and frequency shifting methods and apparatus of the present invention. The original audio signal 12 might have a spectrum like that shown in plot 14. FFT block 16 generates the fast
20   Fourier transform of the original signal 12, to allow processing in the frequency domain. The input audio signal is divided into small time segments, and each is subjected to frequency analysis. Processing block 18 performs the scaling and transposing (or compression and frequency shifting) functions, described in more
25   detail below. Block 20 performs the inverse fast Fourier transform function on the scaled and transposed spectrum, to

compose the output audio signal 22, equal in duration to the original signal. The output signal is then provided to the listener with appropriate amplification to insure audible speech across the usable frequency range.

5   Plot 24 shows how the spectrum of plot 14 would be modified by the processing of Figure 1, given a compression ratio of 50%, or compression factor of 0.5, and no additional transposition of the spectrum. This particular set of processing parameters would be useful for a listener with hearing loss in the

10   high frequency ranges. All of the information that was located at higher frequencies has been proportionally shifted to lower frequencies, where the listener can hear it. More importantly, by proportionally shifting the spectral components the lawful relationship between spectral peaks associated with speech

15   signals is maintained so the listener can understand the information. The particular selection of the amount of compression would be determined by the hearing loss of the user. Compression factors of 0.9, 0.8, 0.7, 0.6, and 0.5 have been accomplished in the lab. Compression factors of up to .99 should

20   work well.

        For a person with hearing loss in low frequency ranges, the compression might be accompanied by a frequency shift upward of, for example 100 Hz, to shift the speech spectrum into the region of usable hearing.

25   A number of different methods may be used to proportionally compress the FFT data, and do the optional additional frequency shifting. Figures 2-7 show examples of how this may be accomplished. Note that optional block 26 indicates

that the time domain signal may be trimmed to ensure that the input signal and the output signal have the same duration. This block is used as shown in Figures 3, 6, and 7, and described in the accompanying text below. Each compression technique will

5   compress the frequency range of the input audio signal in order to fit within the frequency range in which the listener can utilize amplified sound. The general principle is that each frequency is shifted by the same ratio; thus preserving the relative spectral shape, one of the most important invariant cues for speech

10   recognition across various speakers.

        Figure 2 illustrates a simplified block diagram 18a illustrating a first preferred embodiment of proportional compression step 18. Figure 2 is simplified for clarity, showing only processing of the lower portion of the complex frequency

15   spectrum, which is, in fact, symmetrical. The method of Figure 2 is extremely simple. The output of FFT block 16 is a complex array 52 of data representing amplitudes at various frequencies. The compression/frequency shift algorithm 18a simply maps the data, preferably using linear interpolation to minimize data loss,

20   from bins in input array 52 to a smaller number of bins in output array 54. For an input array of size 4096 and a compression ratio of 50% for example, the values associated with input array points 1 through 2048 are mapped to output array points 1 through 1024 (and likewise values above the nyquist frequency, which is

25   located at the center of the array, are mapped to output array 3072 to 4096 as shown in Figure 4). If a compression factor of .67 were desired, linear interpolation between the values of

approximately three input array bins provide values for two
output array bins. Obviously, some frequency resolution is lost in
this mapping, as would be expected in fitting the audio input data
into a smaller output spectrum.

5   If the spectrum is to be frequency shifted in addition to the
proportional compression, this is accounted for in the same
mapping step. If the data is to be frequency shifted up by 100 Hz,
for example, and 100 Hz corresponds to point 47 in the output
array, then input array points are mapped between points 47 and

10   4049 (Figure 5 shows the compression and frequency shifting
process in detail).

          Figure 3 is a simplified block diagram 18b illustrating a
second method of proportional compression 18 along with
frequency shifting according to the present invention. Again,

15   Figure 3 is simplified for clarity, showing only processing of the
lower portion of the complex frequency spectrum, which is, in
fact, symmetrical. In the method of Figure 3, input array 52
(which is the result of FFT operation 16) is padded with zeroes,
preferably inserted in the center of the array, around the nyquist,

20   and mapped onto output array 54 as shown. Output array 54 is
twice as large as input array 52, for 50% compression (the size
of the pad determines the amount of compression). Figures 6 and
7 show in more detail the method by which the zero pad is added
to the complex array generated by FFT step 16.

25   After IFFT 20 is performed, output (time domain) data 22 is
trimmed to the size of the original input signal 12 (block 26 of
Figure 1), so that output signal 22 has the same duration as input
signal 12. This trimming may be accomplished in a number of

ways. For example, points may be trimmed off the beginning of the array, the middle of the array, or the end of the array (or any combination of the forgoing). The particular scheme is chosen to give the most comprehensible output signal for the listener.

Figure 4 illustrates in more detail how the compression step 18a of Figure 2 is accomplished for an example of 50% compression (step 18a-1). Note that adjacent frequency bins from array 52 are linearly interpolated and placed into the bins at the ends of array 54, away from the nyquist frequency at the center of the arrays.

Figure 5 illustrates in more detail how the compression step 18a of Figure 2 is accomplished, along with frequency shifting, for an example of 50% compression (step 18a-2). As in the process of Figure 4, adjacent frequency bins from array 52 are linearly interpolated and placed into the bins at the ends of array 54, but the bins in which they are placed are shifted toward the center enough to accomplish the desired frequency shift. For example, if the data is to be frequency shifted up by 100 Hz, for example, and 100 Hz corresponds to point 47 in the output array, then input array points are mapped between points 47 and 4049.

Figure 6 illustrates in more detail how the compression step 18b of Figure 3 is accomplished, along with frequency shifting for an example of 50% compression (step 18b-1). In the particular example of Figure 6, frequency shifting (by one point, for simplicity) is shown in addition to a compression of 50%. Figure 7 illustrates in more detail how compression step 18b of Figure 3 is accomplished, without frequency shifting, for an example of 50% compression or scaling (step 18b-2). Since no

frequency transposing is to be done, data from the bins of input array 52 are mapped into the endmost bin of output array 54.

5   While the exemplary preferred embodiments of the present invention are described herein with particularity, those skilled in the art will appreciate various changes, additions, and applications other than those specifically mentioned, which are within the spirit of this invention.

What is claimed is:

CLAIMS

1.   A hearing aid for proportionally compressing a signal representing an input audio signal to a usable portion of the sound spectrum in the frequency domain, said hearing aid comprising:

a fast Fourier transform (FFT) block, for forming the FFT of

5   the input signal;

a scaling block, for proportionally compressing the FFT of

the input signal into a usable portion of the sound

spectrum; and

an inverse fast Fourier transform (IFFT) block, for taking

10   the IFFT of the compressed FFT of the input signal and

providing it as an output signal.

2.   The hearing aid of claim 1, wherein:

the FFT block includes an input array of frequency bins, and

said FFT block divides the FFT of the input signal into

said input array of frequency bins; and

5   the scaling block includes an output array of frequency bins,

and said scaling block maps the data from the input

array bins into a smaller number of output array bins

to form the scaled FFT signal, the ratio between

mapped output array bins and input array bins

10   determining the amount of scaling accomplished.

3.   The hearing aid of claim 2, wherein the amount of scaling accomplished is between about 0.5 and 0.99 compression factor.

4.   The hearing aid of claim 2, wherein the scaling block further accomplishes frequency shifting by mapping the data from the input array bins to shifted output array bins according to an amount of frequency shifting desired.

5.   The hearing aid of claim 4, wherein the amount of scaling accomplished is between about 0.5 and 0.99 compression factor.

6.   The hearing aid of claim 4, wherein the frequency shifting accomplished is approximately 100 Hz.

7.   The hearing aid of claim 1, wherein:
      the FFT block includes an input array of frequency bins and
            divides the FFT of the input signal into said input
            array of frequency bins;
5   the scaling block includes an output array of frequency
            bins,said output array being larger than said input
            array according to a desired amount of compression,
            and said scaling block maps the data from the input
            array bins into output array bins to form the scaled
10   FFT of the input signal; and
      said hearing aid further includes a trimming block for
            trimming the output signal in the time domain.

8.   The hearing aid of claim 7, wherein the amount of scaling accomplished is between about 0.5 and 0.99 compression factor.

9.   The hearing aid of claim 7, wherein the scaling block

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further accomplishes frequency shifting by mapping the data from the input array bins to shifted output array bins according to an amount of frequency shifting desired.

10.   The hearing aid of claim 9, wherein the amount of scaling accomplished is between about 0.5 and 0.99 compression factor.

11.   The hearing aid of claim 9, wherein the frequency shifting accomplished is approximately 100 Hz.

12.   A hearing aid for proportionally compressing and frequency
shifting a signal representing an input audio signal to a usable
portion of the sound spectrum in the frequency domain, said
hearing aid comprising:

5   a fast Fourier transform (FFT) block, for forming the FFT of
                   the input signal;

       a scaling block, for proportionally compressing and
              frequency shifting the FFT of the input signal into a
              usable portion of the sound spectrum; and

10   an inverse fast Fourier transform (IFFT) block, for taking
              the IFFT of the scaled FFT of the input signal and
              providing it as an output signal.

13.   The hearing aid of claim 12, wherein:
       the FFT block includes an input array of frequency bins, and
              said FFT block divides the FFT of the input signal into
              said input array of frequency bins; and

5   the scaling block includes an output array of frequency bins,
              and said scaling block maps the data from the input
              array bins into a smaller number of output array bins
              to form the scaled FFT signal, the ratio between
              mapped output array bins and input array bins

10   determining the amount of scaling accomplished, and
              wherein the scaling block accomplishes frequency
              shifting by mapping the data from the input array bins
              to shifted output array bins according to an amount of
              frequency shifting desired.

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14. The hearing aid of claim 13, wherein the amount of scaling accomplished is between about 0.5 and 0.99 compression factor.

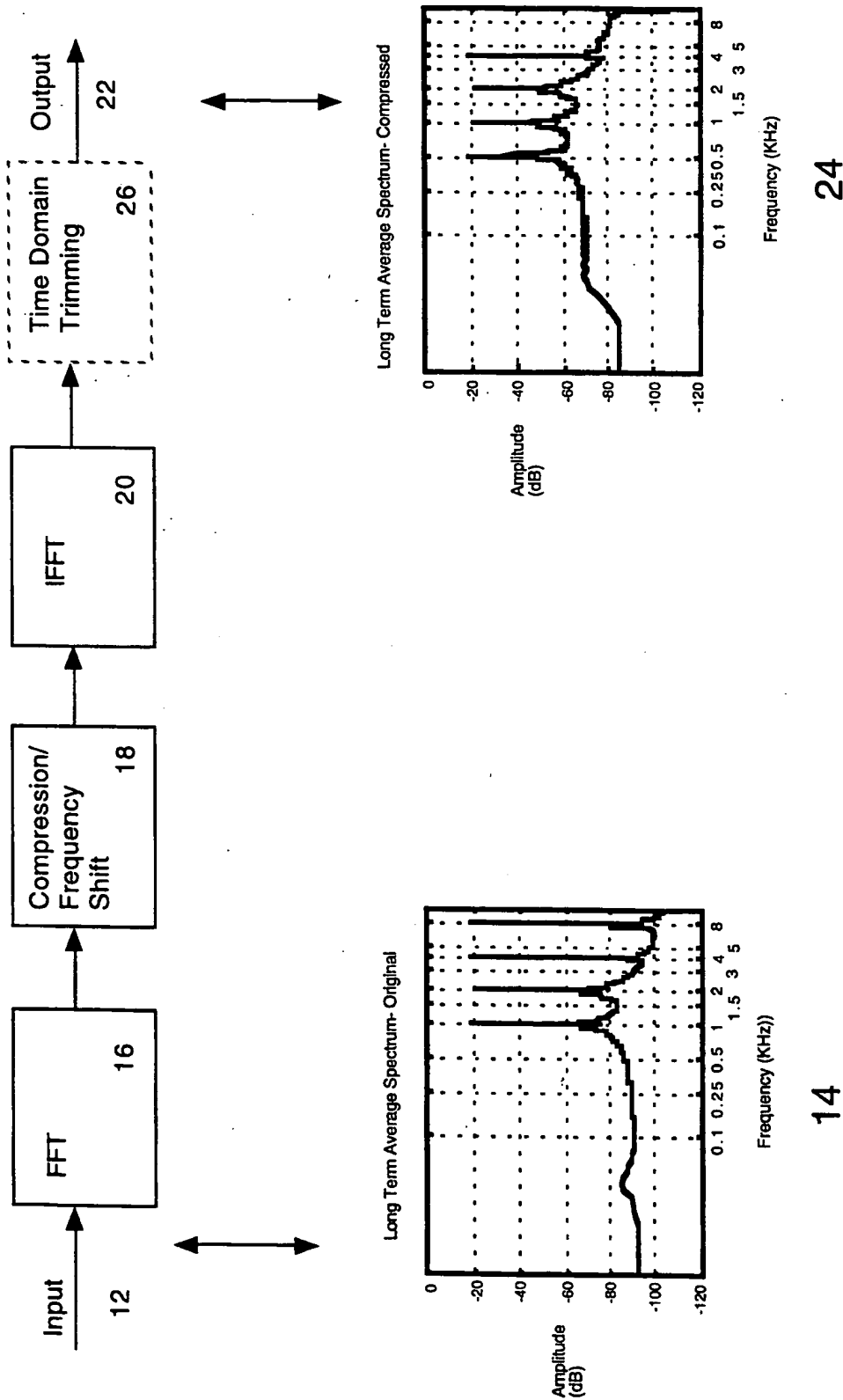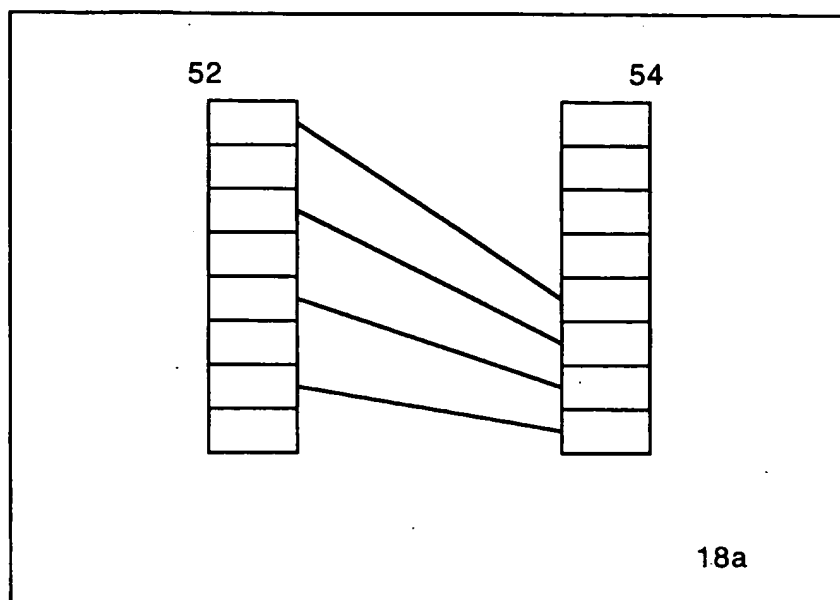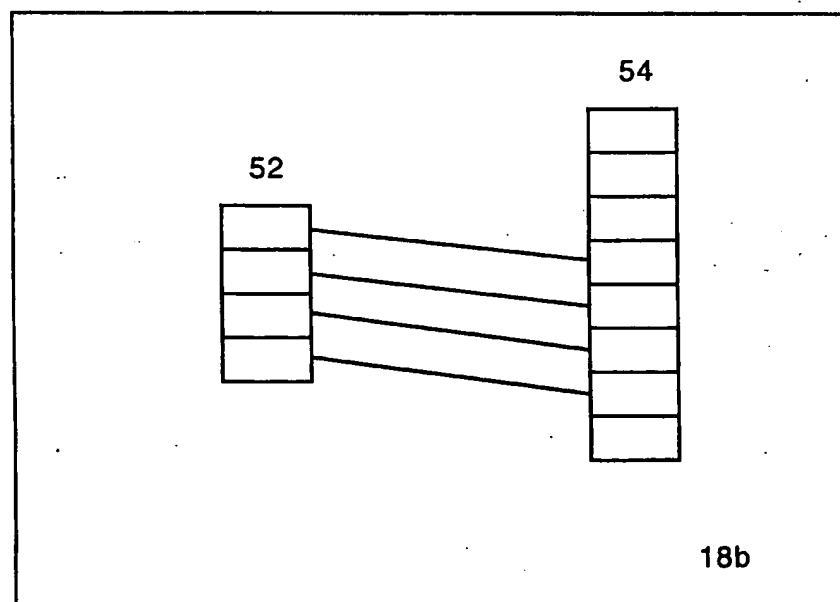15. The hearing aid of claim 13, wherein the frequency shifting accomplished is approximately 100 Hz.
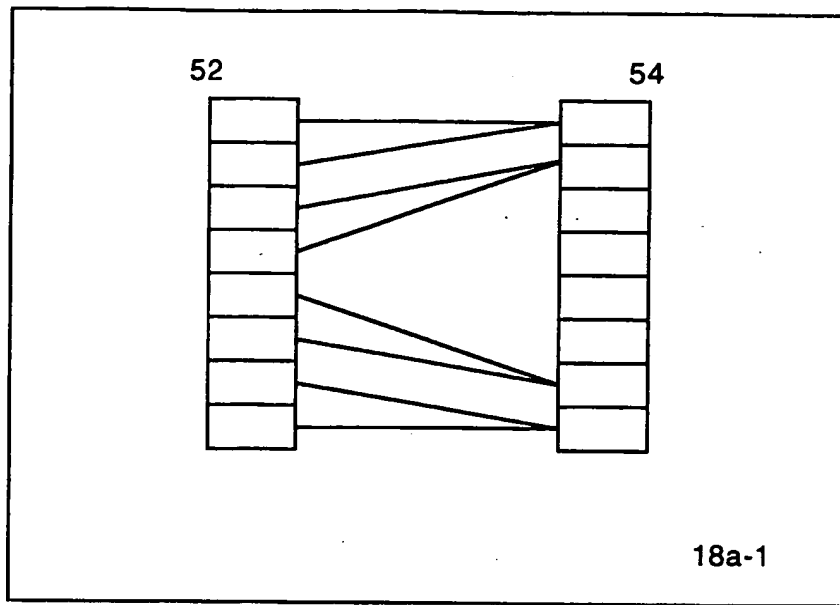
Figure 1

Figure 2

Figure 3

Figure 4
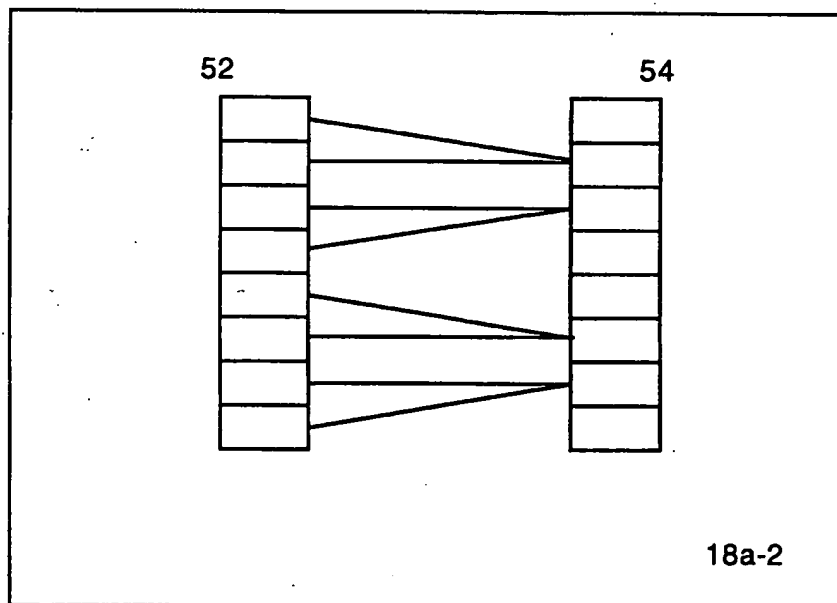
Figure 5
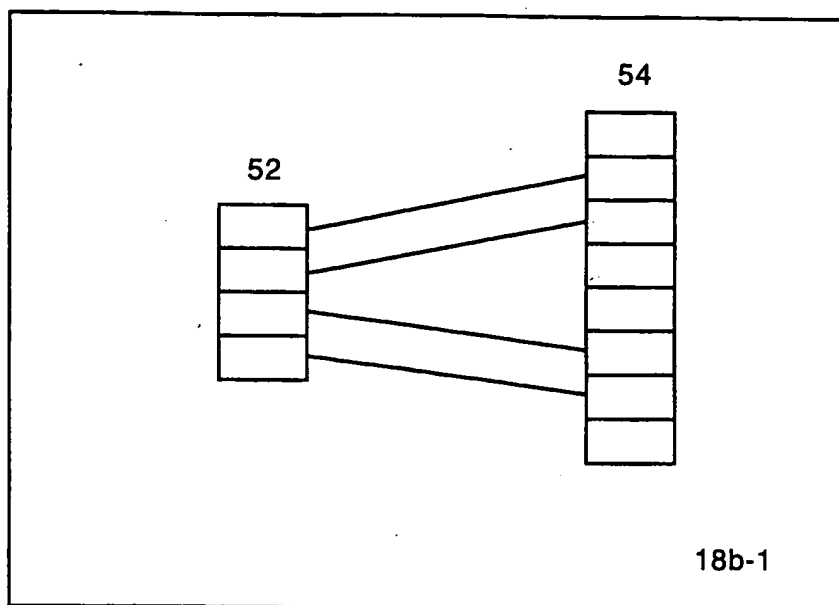
Figure 6
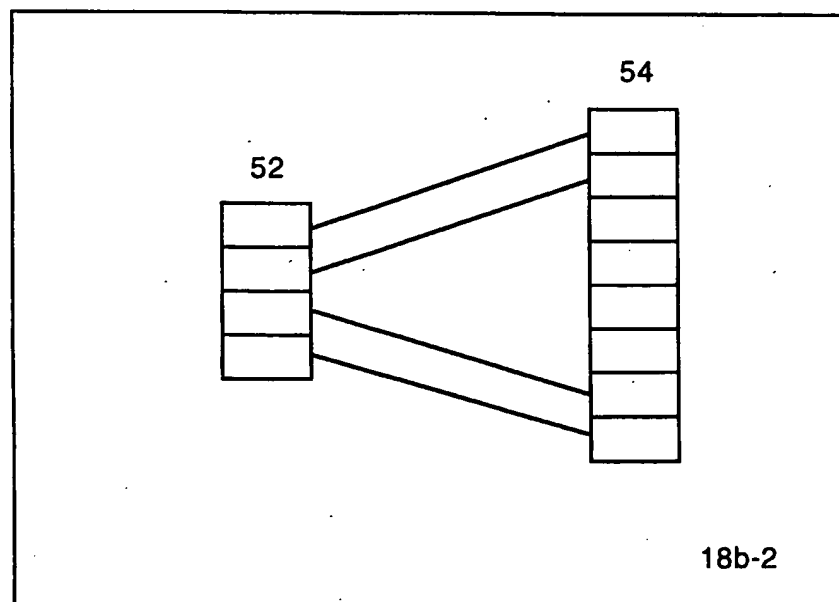
Figure 7

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 6   H04R25/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

.IPC 6   H04R   G10L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 054 450 A (LAFON JEAN CLAUDE) 23 June 1982 see page 3, line 1 - page 10, line 12; figures 1,2	1-3,5,6, 8,10-12, 14,15
Y		4,7,9,13

X	DE 17 62 185 A (BIONDI EMANUELE & BIONDI LEONARDO) 16 April 1970 see page 5, paragraph 3 - page 6, paragraph 5 see page 8, paragraph 3 - page 10, paragraph 2; figure 1	1-3,5,6, 8,10-12, 14,15
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| X | Further documents are listed in the continuation of box C. | | X | Patent family members are listed in annex. |

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
2 February 1999	24/02/1999

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category'	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	MIZUNO H ET AL: "Voice conversion algorithm based on piecewise linear conversion rules of formant frequency and spectrum tilt" SPEECH COMMUNICATION, vol. 16, no. 2, February 1995, pages 154-164, XP004024957	4,7,9,13
A	page 154, left-hand column, line 1 - page 158, left-hand column, line 7	1,12

Y	MAZOR M ED AL: "Moderate frequency compression for the moderately hearing impaired" JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA, vol. 62, no. 5, November 1977, pages 1273-1278, XP002091968 USA page 1273, left-hand column, paragraph 1 - page 1275, right-hand column, paragraph 1 page 1276, right-hand column, paragraph 3 - page 1277, right-hand column, paragraph 1	4,7,9,13
A		1,12

Y	US 3 819 875 A (VELMANS M) 25 June 1974 see the whole document	4,7,9,13

A	US 5 029 217 A (CHABRIES DOUGLAS M ET AL) 2 July 1991 see column 11, line 61 - column 13, line 6; figure 5	2,4,7,9, 13

A	US 3 385 937 A (LAFON JEAN-CLAUDE) 28 May 1968 see the whole document	1,12

2

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
EP 0054450	A	23-06-1982	FR	2494988 A	04-06-1982
DE 1762185	A	16-04-1970	NONE		
US 3819875	A	25-06-1974	GB	1340105 A	12-12-1973
US 5029217	A	02-07-1991	AU	596633 B	10-05-1990
			AU	6767187 A	23-07-1987
			CA	1284529 A	28-05-1991
			DK	33587 A	22-07-1987
			EP	0252205 A	13-01-1988
			JP	62224200 A	02-10-1987
US 3385937	A	28-05-1968	BE	643118 A	15-05-1964
			DE	1261169 B	
			DK	135140 B	07-03-1977
			NL	6401211 A	17-08-1964